

Semi-annual EOS Contract Report -- Report #48

Period: July 1 - December 31, 1995

Remote Sensing Group (RSG), Optical Sciences Center (OSC) at the University of Arizona

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Contract Number: NAS5-31717

Report compiled by: K. Thome

Summary: Work by members of the RSG during the past six months consisted of Science Team support activities including attendance at meetings related to MODIS, work on the atmospheric correction of ASTER data, and assisting in a stray light study for MODIS. Significant progress was made on the SWIR CCR with reflectance measurements of possible interior paints, characterizing our Optronics monochromator for filter measurements, development and initial fabrication of mechanical parts of the system, and work with the system's lock-in amplifier. Work continued on developing the BRDF and diffuse-to-global meters. We continued improvements to our calibration facilities and blacklab including characterizing humidity effects in our calibration laboratory. Preliminary results were obtained from a cross-calibration study of HRV and TM and we developed the capability to process our field data for hyperspectral sensors. Field work activities were continued with an October trip to White Sands and work to upgrade our measurement capabilities.

Introduction: This report contains twelve sections. The first nine sections present different aspects of work performed under our contract. If appropriate, each section covers five areas; task objective, work accomplished, data/analysis/interpretations, anticipated future actions, and problems/corrective actions. The nine sections are: 1) Science team support activities; 2) Cross-calibration radiometers; 3) Mobile laboratory; 4) Bi-directional reflectance distribution function (BRDF) meter; 5) Diffuse-to-global meter; 6) Calibration laboratory; 7) Algorithm and code development; and 8) Field experiments and equipment. The ninth section contains information related to faculty, staff, and students, and the tenth section summarizes papers published, submitted, and in preparation.

Science Team Support Activities: This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the past six months this included the attendance at team and other related meetings and completing assigned action items.

ASTER Activities: P. Slater, P. Spyak, and K. Thome met in Tucson with several members of the ASTER Science team on October 17 and 18 to discuss algorithm validation plans and ASTER data collection prioritization. K. Thome sent comments and suggestions to ASTER Science Team Leader, A. Kahle, on a proposed method for ASTER data collection prioritization. He also sent comments to G. Geller of JPL regarding ASTER Level-1 quality assessment documentation. Thome emailed comments on ASTER DEM requirements for the VNIR/SWIR atmospheric correction to M. Pniel of JPL. Slater and Thome attended the ASTER U. S. Science Team Meeting November 13 in Tokyo where Slater presented a summary of the Wallops Island Vicarious Workshop. The two then attended the Joint ASTER Science Team Meeting November 14-17 in Tokyo. Slater presented plans for vicarious calibrations for the spring of 1996 during the plenary session and co-chaired the Radiometric Calibration Working Group. Thome presented the current status of the VNIR/SWIR LUT and validation plans for the solar reflective range to the Atmospheric Correction Working Group as well as the RSG's vicarious calibration plans to the Radiometric Calibration Working Group.

MODIS Activities: S. Biggar and Slater attended the MODIS calibration review on 18 July. Slater presented a description of the RSG's role in the calibration of MODIS with an emphasis on the vicarious calibration approach. Slater and Thome attended the MODIS Vicarious Calibration Workshop held at Wallops Island from August 7-10. Thome presented an overview of the vicarious calibration efforts of the RSG and Slater presented proposed methods for reconciling the different sets of vicarious results from various groups anticipated in the EOS era. Slater met with J. Butler and D. Starr on August 23 to summarize some of the conclusions from the Vicarious Calibration Workshop and discuss how joint field campaigns might be organized. Biggar, Slater, and P. Spyak attended the MODIS Calibration Peer Review at SBRC from September 12-15 and provided comments on the review to B. Guenther.

Slater met with N. Fox of the NPL. Discussions included the subject of the contamination of small apertures used for calibration purposes. In addition to the calibration of SOLSTICE, this

contamination problem relates to the screen used for the MODIS Solar Diffuser Stability Monitor and the partial-aperture, direct-solar calibrator on Landsat-7. Slater forwarded a short summary of the topic written by Fox to Guenther.

Spyak reviewed Breault Research Organization's stray-light analysis on cloud-edge scatter and earth-scene integrated scatter for the nominal and improved surface scatter levels and various contamination levels. He discussed his findings with G. Godden of GSFC. Spyak also met with Godden at the MODIS Calibration Peer Review and the two concluded that, with respect to far-field scatter, a cleanliness level of 300 on the fore optics will dominate the system scatter. Spyak wrote a section for the MODIS Calibration Plan on transfer radiometer and round robin measurements and submitted it to Godden. Slater wrote a section for the Calibration Plan on Vicarious calibration. Spyak discussed possible contamination/degradation effects of MODIS due to interplanetary dust with G. Godden of GSFC and attended the MODIS TIR ATBD Audit at The University of Wisconsin November 7-9. Biggar attended the MODIS Science Team Meeting, November 14-17.

Biggar, Slater, and Spyak met in Tucson on October 25 and 26 with B. Guenther and H. Park of GSFC to discuss MODIS calibration using the solar diffuser. Spyak reviewed the MODIS Calibration Management Plan and emailed comments to Guenther. Biggar, Slater, and Spyak attended an MCST audit held in Tucson, December 11-14. Later in the same week, Slater attended the AGU meeting in San Francisco and presented an invited poster titled "MODIS Calibration" authored by Slater, Biggar, Spyak and Thome. Biggar and Slater attended the MODIS Calibration Software CDR at SAIC, Greenbelt, followed by the MODIS Calibration ATBD'95 review, during the period December 18 - 20.

Other EOS Related Activities: A paper titled "Unified approach to pre- and in-flight satellite-sensor absolute radiometric calibration" authored by Slater, Biggar, Palmer and Thome was presented at the EUROPTO meeting in Paris and the written version was submitted to the proceedings of the SPIE. Revisions are now in progress for a version to be submitted to a peer-reviewed journal. The paper emphasizes the value of the sun in linking preflight and in-flight calibration of a sensor with the calibration of the radiometers used for vicarious calibration and the field validation of higher level data products. Slater discussed SeaWiFS plans with R. Santer (a co-investigator on our SeaWiFS grant) at the Universite du Littoral, near Calais.

Thome sent R. Barnes of SeaWiFS MODTRAN transmittance output to study the effect of oxygen absorption in SeaWiFS processing. R. Parada completed and submitted our annual SeaWiFS status report. Biggar, Slater, and Thome met with M. Dingirard of CNES to discuss possible calibration research for the sensor Vegetation.

Biggar and Slater spent the week of October 30 at ERIM conducting a cross comparison of calibration sources used for HYDICE. The use of Biggar's EOS cross-calibration radiometer was successfully tested but unfortunately weather did not permit a planned solar-radiation-based calibration of HYDICE, as a rehearsal for a similar calibration planned for MODIS. Slater and Thome are planning a major joint IST vicarious calibration campaign from May 30 to June 7, 1996. The sites to be used are Lunar Lake and Railroad Playa, Nevada. Science Team Members from ASTER (including several Japanese), MISR and MODIS have said they will participate. Several aircraft sensors may support the campaign including AAS (the ASTER Airborne Simulator), AES (an airborne version of TES), AVIRIS, a Cessna aircraft carrying RSG instruments, an ER-2 carrying Peter Abel's spectroradiometer, MAS, and TIMS. B. Crowther sent solar radiometer data collected in Hawaii to J van den Bosch of the MISR calibration/validation group to compare their retrieval algorithms to ours. C. Gustafson presented a poster on our EOS calibration work for the University of Arizona's Student Showcase 1995. The Showcase is an annual event held by the university during Homecoming weekend to display to the general public current research being done by students. Parada attended the Bio-Optical Oceanography summer course at Friday Harbor Labs in Washington during July and August.

Cross-Calibration Radiometers: This section describes work to design, fabricate, test, and calibrate a set of preflight cross-calibration radiometers (CCRs). These radiometers are to cover the wavelength region from 400 to 2500 nm. To accomplish this, two radiometers will be constructed, each optimized for a specific portion of the spectrum. They will have very low stray light and polarization responses, exhibit sharp, well-defined fields of view and spectral response profiles, and be ultrastable with respect to temperature and time. The radiometers will be used to provide an important independent calibration and cross-calibration of the calibration facilities used by the Phase C/D contractors.

VNIR CCR: The objective of this project is to design and build a 400- to 900-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance using pressed PTFE (Algoflon) targets. Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters and two precision apertures determine the throughput. Heating the detector assembly, filters, apertures, and amplifier to a stabilized temperature, a few degrees above ambient, provides thermal control of the system. The system uses a high accuracy voltmeter connected via GPIB to digitize the amplifier output. A commercial datalogger digitizes ancillary information such as detector temperature, and controls the amplifier gain through digital output ports. This datalogger sends the serial digital data to an MS-DOS compatible computer.

Biggar and B. Nelson continued work on the prototype and new version of the VNIR CCR. They examined possible noise sources in the prototype to ensure the new version does not have the same problems. Some of these problems will be solved with software modifications while others will require modifying the hardware. The two found several methods to reduce ground reference problems. Biggar ordered and received heater controllers for the new CCR and modified the radiometer software to monitor the six-inch spherical-integrating source. C. Burkhardt changed the prototype's housing. Biggar and R. Kingston finished software to allow use of an automated filter wheel which has been built.

SWIR CCR: The objective of this project is to design and build a 1000- to 2500-nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will be compared to NIST-traceable standards of spectral irradiance and pressed PTFE (Algoflon) targets. The system is designed around an InSb detector. Linearity, repeatability, and stability will all be limited by electronics, not the detector itself.

Spyak discussed with vendors the specifications for the cold filter, dewar window, and bandpass filters for the SWIR CCR and all three were ordered. He received the drawing packages on the baffle/filter/detector assembly from Cincinnati Electronics, reviewed it, and discussed changes with them. Spyak ordered and received the valve operator for the system's dewar. Spyak and J. LaMarr tested the lock-in amplifier using software developed by LaMarr.

Spyak completed SWIR-CCR-cold-filter, spectral transmittance measurements needed by

Cincinnati Electronics to perform quantum efficiency calculations and shipped the cold filter to Cincinnati Electronics. The dewar window delivery was delayed but it finally arrived and has been sent to Cincinnati Electronics. The bandpass filters were coated and are being assembled by Barr.

Spyak and Burkhart discussed mechanical design concepts for the system and Spyak completed mechanical drawings for the radiometer. Burkhart began fabricating mechanical parts. He completed the light seal cutters, three apertures, the filter wheel assembly, chopper assembly, dewar mount, baseplate, and stray light shield. Burkhart is also machining the SWIR CCR parts to reduce weight and began bead-blasting parts to prepare them for anodization.

Burkhart expects to complete machining parts for the SWIR in early January, 1996 and will test the fit of the dewar assembly when it arrives. All parts will be anodized before final assembly. Spyak had hoped to complete the radiometer and begin characterizing it before the end of 1995, but delays in receiving the filters and dewar window have caused this date to slip. The initial assembly of the instrument is expected to occur in January, 1996.

Mobile Laboratory: The objective of this task is to provide a mobile laboratory for 1) storage and transportation of equipment; 2) electricity (AC and DC) for equipment; and 3) shelter from the sun, heat, and cold for computers and people during measurements and for all of our equipment overnight at experiment sites.

The mobile laboratory made its maiden trip to White Sands Missile Range on which it operated smoothly. The laboratory was also used for a brief period during the campaign to provide electric power when an electrical circuit in the Chuck Site facility failed and an alternative had to be used. Of course, the trip also pointed out several things which need to be done to improve the laboratory. We plan to use the next six-month reporting period to make these improvements. The laboratory will be used for a March campaign to a Nevada playa and a May campaign to Railroad Playa.

BRDF Meter: The objective for this task is to design and construct a device, and develop software for measuring the directional reflectance and inferring the bi-directional reflectance

distribution function of the ground. The basic design incorporates a fisheye lens and a CCD-array detector.

M. Brownlee examined light levels for the BRF meter and found the levels for the UV band to be an order of magnitude smaller than the signal level of the other three bands. She investigated methods for rotating and translating the camera for the system's flat-field calibration and determined our 40-inch spherical-integrating source is spatially-non-uniform but repeatable. Brownlee investigated measuring the camera's spectral response with the Optronic monochromator and designed the filter holder for the BRF-meter's camera system. Burkhart machined a set of filter adaptor rings for the system.

Brownlee investigated beam traps and black surfaces for testing stray light in the camera and ordered a beam trap and a beam dump. She began investigating replacement of the camera window with an absorption filter. The current window is two-inch diameter, 1/8-inch thick, fused silica. She is considering a correction filter which is more transparent in the UV than at longer wavelengths. She talked to J. Palmer of OSC regarding the replacement of the camera's exit window with a neutral density filter. Brownlee decided to use neutral density filters to determine window transmittance requirements rather than extrapolating digital counts measured at shorter exposure times and purchased two Wratten filters for this purpose. She determined the camera head's shutter speed is not repeatable at 10 ms and had the shutter replaced by one which is five times faster. She collected data in the blacklab to test its repeatability. Measurements were made to determine maximum light levels with the new shutter. The new shutter allows Brownlee to place a filter before the exit window rather than the more complicated case of replacing the exit window.

Using IDL, Brownlee began developing BRF model data based on the 1995-04-01 White Sands data to use for a BRF retrieval sensitivity study. She developed software to open stored image files, and calculate image statistics of a 10 x 10 pixel region. The image data are often shifted by 11 pixels and this is also handled in the processing.

Brownlee made pre-trip plans for determining BRF of Railroad Playa by fitting the camera's chiller with additional quick release tubing to facilitate draining and filling. Based on information from Brownlee, B. Pratt of OSC machine shop extended the tripod boom to place the camera one meter from the tripod. The same boom was modified to hold an Exotech

radiometer. Brownlee wrote data acquisition software to operate automatically with the BRF camera and to recover from power failures. Brownlee tested the BRF camera with a generator but was unable to get a UPS to accept power from a portable generator and the camera was not used on the Railroad Valley trip. Brownlee processed and investigated BRF data collected in October and November at Railroad Valley as a function of both view angle and scatter angle.

Diffuse-to-global meter: The objective of this task is to design and build an instrument to collect diffuse-to-global irradiance data. By comparing the diffuse downwelling irradiance to the global (direct plus diffuse), an improvement to the atmospheric correction may be made which reduces the uncertainty of the reflectance-based method. Currently, global irradiance data are collected using a radiometer viewing a reflectance panel and diffuse data are collected by manually positioning a parasol to shade the panel. The diffuse-to-global meter will collect these data automatically and more repeatably.

Burkhart machined a fixture for Crowther which will be used for preliminary machining tests of the Spectralon material used for the diffuse-to-global meter. Burkhart and Crowther examined the spheres supplied by Labsphere for the diffuse-to-global meter. Several blemishes were found where rust and oil were absorbed by the Spectralon at the attachment points between the hemispheres which make up the spheres. These blemishes are far enough away from the internal spherical surface that they should not be a problem. Another problem is that there are visible seams between the two hemispheres. Burkhart and Crowther machined a small sample of Spectralon and found good results with using a sharp tool, a high rotation rate, and a low feed rate. Burkhart will still have to machine special tools to hold the sample securely while it is machined.

Crowther gathered information on quartz and glass domes to be used on the sphere during dusty or otherwise marginal weather conditions. Burkhart grey-anodized a test plate for Crowther to test the reflectance of this material for use in the diffuse-to-global meter. He is presently revising the sphere designs after consultation with Burkhart. Burkhart machined a prototype of the shadowing disk for the diffuse-to-global meter. Crowther continued revising the occulter and other mechanical portions of the diffuse/global meter in consultation with Burkhart.

Crowther began work on and completed LiCor control software. He encountered difficulties due to incomplete hardware documentation and a lack of hardware handshaking on the LiCor. He researched spherical astronomy related to predicting solar position and selected "Astronomical Algorithms" by Jean Meeus as a reference for coding a solar position algorithm in C. He compared solar position results from this code to those of the Naval Observatory program MICA and the algorithms used by B. Schmid. Crowther's code predicts the solar position with an accuracy of better than 0.01 degrees. He reviewed two papers written on the topic of airmass calculation and found the retrieved airmass from a post-refraction method (Kasten and Young) differs from a pre-refraction method (Young) by a few percent at high airmass.

Crowther investigated the motion control problem and identified two options and will continue to look for others. He started calculating rotational inertias and center of mass points for the rotation motions in order to correctly select stages and motors. He anticipates finishing these calculations and ordering the stages, motors, and motor controllers in January, 1996.

Crowther submitted a paper entitled "Computer modeling of integrating spheres" to *Applied Optics*.

Calibration Laboratory: The objective of this project is to develop a calibration laboratory that will provide the necessary high-radiometric-accuracy standards and characterization set-ups for 1) the cross-calibration radiometers and 2) the field and aircraft radiometers needed for preflight algorithm and code validation and the actual in-flight calibration of the EOS multispectral imaging sensors beyond 1998.

Spyak started characterizing the Optronic monochromator for SWIR CCR filter measurements. He received the cold filters and started measuring their spectral transmittance over the range from 275 - 6500 nm. He performed a spectral calibration for gratings 2 and 3 (about 900 - 3500 nm), and checked the calibration of grating 1 above 800 nm. All three gratings were brought to within specification (0.05% of the set wavelength). Spyak also performed stability tests over the range from 1020 - 4600 nm and concluded a two-hour warm-up time is required to achieve about 0.5% one-hour stability for wavelengths greater than about 1240 nm. At 1020 nm a warm-up time of 3 - 4 hours is necessary to achieve 0.5% one-hour stability.

Spyak further characterized the monochromator for the cold-filter measurements. He determined that in the 3 - 3.6 μm range., the out-of-band rejection measurements should be about 0.00001 but are one to two orders of magnitude larger. Studies indicate that blocking filter number 5 of the Optronic is the problem and it may have an out-of-band leak. For in-band measurements this is not a significant problem.

LaMarr found the germanium and pyroelectric detectors of our Optronic monochromator exhibit random fluctuations in the signal too large to attribute to noise. The problem was fixed by replacing a microprocessor in the unit. We received the InSb detector for the monochromator. Spyak received a ceramic glower for use as an infrared source.

LaMarr began measurements of the autotracker filters with the Optronic monochromator but the system again failed making the results questionable, so they will be redone. The problem is similar to one we have had in the past with the chopper malfunctioning. LaMarr and Spyak installed a new chopper electronic board provided by Optronic. This has reduced the problem but the chopper is still not positioning properly. The chopper and two chopper electronic boards were sent to Optronic for repair or replacement. Upon receipt of the repaired units we found a new problem with the chopper. The chopper electrical controller and cabling were sent to Optronic for repair. We received a usable unit the last week of December. We will once again begin the process of calibrating and characterizing the system once the repaired units are returned.

LaMarr developed software to process the temperature and relative humidity data collected using the calibration laboratory sensors. He used this software to examine temperature and humidity data collected in the calibration laboratory to determine the effects of changes in these quantities on calibration measurements. Reference data were also collected while purging the system with dry nitrogen. The results have been compared to MODTRAN output for varying spectral resolution, spectral sampling, and relative humidity.

LaMarr measured the diffuse hemispherical reflectance of paint samples for the interior of the SWIR CCR, including Krylon ultra-flat black spray paint, ECP2200, Cat-a-lac black, Ebinol C, anodized bead blasted aluminum, and Edmund Scientific black fuzzy paper. One interesting result is the anodized aluminum has a hemispherical reflectance of less than 3.5% from 300-700 nm, greater than 50% reflectance at 1000 nm, and nearly 75% at 1800 nm.

LaMarr received three more anodized samples from Burkhart to study this effect further, black anodize on bead blasted aluminum, black anodize on smooth aluminum, and gray anodize on bead blasted aluminum . All three exhibit a large increase in reflectance outside of the visible. The paint spectral reflectance is fairly flat through 1800 nm and the paper's reflectance increases outside of the visible. The paper may become transparent at longer wavelengths causing the measured reflectance to be dominated by the reflectance of the aluminum plate to which it was mounted.

Spyak and Schmid set up and performed absolute calibration measurements of Schmid's solar radiometers. Spyak and Schmid discussed results of spectral response measurements and the absolute calibration measurements. Spyak and Biggar set up the blacklab to absolutely calibrate the VNIR CCR and compare the secondary standard lamp to the NIST standard lamp. R. Parada, Biggar and Schmid compiled the various "calibrated spectral irradiance" results obtained from the Optronic FEL #296. These numerous results were obtained from a variety of measurements/instruments. Parada will use the results to redo the laboratory calibration of the MMR for the Lake Tahoe and Ivanpah field campaigns.

NIST is unable to provide hemispherical reflectance measurements of the Algon and Halon samples sent to them in mid-April. Spyak decided to have the samples returned so we can perform the measurements and complete the study. Spyak and LaMarr began tests to study the feasibility of creating 2 foot square Algon samples for calibration purposes. Several "sub-standard" small Algon samples were created and measured. The reason for this was the belief that it will be more difficult to create a "perfect" 2-foot square sample. In all cases, the "sub-standard" samples are as lambertian as the "good" samples. LaMarr developed software to compute reflectance-panel coefficients from raw calibration files.

Algorithm and Code Development: Currently, several algorithms exist to perform our calibration work. The RSG has applied these algorithms as FORTRAN programs which are neither user friendly nor efficiently linked together into a single package. The task objective is to convert these existing codes into ANSI standard C in a user-friendly package with rules-based decision making in the package. The group is now also involved in the atmospheric correction of ASTER data in the solar-reflective portion of the spectrum

Thome modified the Gauss-Seidel radiative transfer code to operate in hyperspectral mode. He modified Biggar's optical depth determination code also to operate in hyperspectral mode and to write the needed input file to the hyperspectral radiative transfer code. Thome also modified the surface reflectance retrieval code to handle the ASD data from Ivanpah Playa and completed processing the reflectance-based calibration of HYDICE using the recently developed hyperspectral code and the panel calibration data obtained from Spyak. Thome worked with A. Murray of JPL to set up the runs for developing the prototype look-up table for the ASTER atmospheric correction. Development of the ASTER LUT has continued and it appears that the automatic generation program developed at JPL is working properly.

Field Experiments and Equipment: The objectives of the field experiments are to test new equipment, determine needed improvements, test retrieval algorithms and code, and monitor existing satellites in much the same way as we shall for EOS sensors.

LaMarr began refurbishing the autotracking (AT) spectropolarimeter. As mentioned above, he started filter transmittance measurements of the interference filters from the AT using the Optronic monochromator and reviewed polarization principles and the dissertations by K. Castle and R. Holm. Using surface solar irradiance data obtained Thome, LaMarr began calculations to determine the maximum expected signals for each spectral band to select the appropriate ND filter to use in solar viewing mode.

Gustafson continued work on the cross-calibration between Landsat-5 TM and SPOT-3 HRV using the October 8 and 9, 1994 data from White Sands Missile Range. Using ASD data of Chuck Site from the April White Sands trip she found the difference between the reflectance at the center wavelengths of overlapping bands for the two sensors to be largest for bands 2 of TM and 1 of HRV (5%). The other two sets of wavelengths (bands 3 of TM and 2 of HRV, and bands 4 of TM and 3 of HRV) were within 1% of each other. Thome determined that BRF effects between the two data sets should be less than 1% based on April, 1994 BRF data. Gustafson did the cross-calibration using the computed reflectance-based calibration of HRV from the October 9 data as the reference. From these results, she computed the surface reflectance for several selected target areas. She then used these reflectances and the October 8 atmospheric data to compute the calibration coefficients for corresponding bands of TM. These

cross-calibration values were compared to the calibration coefficients for TM based on the reflectance-based calibration of October 8. Using a part of Chuck Site as a target, Gustafson found results consistent with the surface reflectance differences between bands. That is, the difference between the ground-based calibration coefficients and the cross-calibration-based coefficients are 0.3-4.3% with the largest value being for TM-band 2 and HRV-band 1. She also found the results to be site dependent with darker targets not as good as brighter targets. Gustafson found several sites for which increasing the size of the target from 90 m \times 90 m to 270 m \times 270 m has little effect on the results. Gustafson submitted an abstract to present this work at IGARSS'96.

Gustafson ordered a new, longer optical fiber for our ASD FieldSpec FR. She scheduled the spectroradiometer to have the second SWIR grating upgraded, received an update to the system's data collection program, and also received a data collection program tailored for the VNIR. This last software will allow us to better examine the temporal variability of the system. Gustafson also modified her ASD processing software used to convert the data to a format suitable for our surface reflectance retrieval. She provided Thome with the formatted ASD data from the Ivanpah Playa data collection. Gustafson also collected ASD data of several soil samples for A. Batchily of A. Huete's group at the University of Arizona. She collected data with the FieldSpec looking at a barium sulfate panel for two 3-hour periods under clear skies to look for any time dependent effects in the system. She also used the FieldSpec to verify the shape of spectral-reflectance curves of several black samples. The system was sent to ASD for installation of the longer fiber and spectrometer upgrades.

Parada began reducing the aircraft data of Ivanpah Playa and Lake Tahoe. Parada discussed results with Santer while he visited the group in July. He learned to read and manipulate HYDICE imagery using an IDL widget supplied by NRL, and ordered June 22 AVIRIS imagery of Lake Tahoe and June 20 data of Ivanpah Playa as well as HYDICE imagery of Lake Tahoe to begin over-water radiance-based calibrations from the June campaign. Parada obtained a summary of in-water measurements taken by the USF group during the June 1995 Lake Tahoe calibration work. Results indicate the calibration of AVIRIS will not be affected by the higher surface scatter from portions of the lake not used for the calibration. Parada looked for local sites for a calibration campaign to compare the radiance- and reflectance-based methods

of calibration over a dark (low-reflectance) land target. He began installing the aquatic radiative transfer code and worked on the geographical registration of HYDICE imagery.

Thome and Schmid set up Schmid's solar radiometer on Mt. Lemmon. Schmid ran the instrument for two weeks, from October 13-27 and coincident data were collected with our solar radiometers on October 14, 15, 20, and 21. Parada and Thome collected data at the Steward observatory on Mt. Lemmon to calibrate our solar radiometers and to perform a Rayleigh-scattering calibration of the MMR as well as test our new met station. Parada reduced the solar radiometer measurements associated with the Rayleigh-based calibration. The data are being compared with data collected by Schmid's instrument. The results from both will be used to compute the downwelled radiance present on the two days in which MMR measurements were made. Thome completed a solar-radiation-based calibration of our MMR using data collected at Lake Tahoe last June and these results will be compared to those of the Rayleigh-scatter approach and laboratory measurements. Parada measured the dimensions of the new met equipment for ordering field cases. He submitted designs for Optronic-MMR-filter mounts to Burkhart.

Crowther, Recker, and Thome shipped the 10-channel solar radiometer to Hawaii where Crowther collected data in support of TIMS overflights. While in Hawaii, Crowther made two attempts to collect Langley data on Mauna Kea but was unsuccessful due to weather. Crowther also wrote software to facilitate processing solar radiometer data from the Fluke Hydra. He and Thome processed the data and sent columnar water vapor amounts to V. Realmuto of JPL.

Crowther, Gustafson, LaMarr, Parada, Spyak, and Thome traveled to White Sands, New Mexico from October 6-10 to collect data for calibrating SPOT-2 and -3 HRVs and a French military satellite. Crowther, Parada, and LaMarr were all trained on the operation of the yokes for reflectance measurements. Gustafson collected reflectance data of the site with the ASD FieldSpec FR. Weatherwise, the trip had clear skies for four out of five overpasses. Thome began to process the data.

K. Scott prepared for a trip to Railroad Valley Playa to check logistics and obtain permission for accessing the playa. The trip was also made to locate and evaluate possible small-footprint calibration sites and determine their location using GPS, remove surface samples from identified areas for spectral reflectance measurements, collect preliminary reflectance and BRF

data of the area, and determine logistics for a trip in November. The trip took place October 25-27. Since the northern and central parts of the 10 by 15 km playa looked the most promising, these areas were explored first. Road conditions were variable from good to very poor (requiring a four-wheel-drive vehicle). Reflectance and BRF data were collected at the most promising and accessible site. Samples of two sites were collected and returned to Tucson for high resolution spectral measurements. Reduction of the reflectance and BRF data has begun.

Brownlee, Parada, and Scott travelled to Railroad Valley Playa November 13-16 to collect satellite cross-calibration data. Data were collected November 14 and 15 for overpasses of NOAA 14 and November 16 for a SPOT-3 overpass. The trip resulted in three days of Exotech-BRF data taken at several view azimuth and zenith angles, and solar azimuth and zenith angles.

Faculty, staff, and students: The personnel presently associated with the RSG are as follows. Faculty: Biggar, Slater, Spyak, and Thome. Staff: Burkhart, Kingston, Nelson, and Recker. Students: Brownlee* (Ph.D.), Crowther* (Ph.D.), Gustafson (Ph.D.), LaMarr (Ph.D.), Parada* (Ph.D.), Scott* (Ph.D.), and Walker* (Ph.D.). Those with an asterisk following their names have passed the Ph.D. Preliminary Examination and are mainly working on their Ph.D. research. Brownlee and Crowther have NASA Fellowships under the Graduate Student Researchers Program, and Parada has a NASA Global Change Fellowship. Walker is self-supported, leaving three graduate students supported by this and other contracts. A visiting scholar, Beat Schmid from the Institute of Applied Physics at the University of Bern, arrived in October to work with the group for four months on solar radiometer related research. Parada began a six-month stay in France to work with Richard Santer on SeaWiFS related topics. Michael Sicard also rejoined the group in December to begin a 16-month stay with us to work on a joint project with Cimel to characterize a recently developed TIR field radiometer.

Publications

Submitted for Peer Review:

Computer Modeling of Integrating Spheres submitted to *Applied Optics*

B. Crowther

ABSTRACT

A Monte Carlo model for predicting the performance of integrating spheres as a function of incident flux direction is presented. The model was developed specifically to aid in the design of integrating spheres used as cosine collectors but is of general applicability. A method of

generating uncorrelated random numbers is discussed. The probability density functions associated with uniform irradiance over a circular entrance port and lambertian reflectors or emitters are presented. A comparison of the model with analytic equations predicting performance for an unbaffled integrating sphere is included. The data generated by the model agree with the analytic solutions for sphere throughput to better than 0.25%.

Presented:

Unified approach to pre- and in-flight satellite-sensor absolute radiometric calibration presented at EUROPTO '95

P. N. Slater, S. F. Biggar, K. J. Thome, and P. R. Spyak

ABSTRACT

The need is identified for a unified approach to the preflight and in-flight absolute radiometric calibration of satellite sensors, which does not depend on the accurate transfer of lamp and detector calibrations from the laboratory to orbit. Such an approach is described that uses the sun to provide the link between preflight solar-radiation-based calibration, in-flight solar-diffuser-based calibration and vicarious calibration.

An example is given of each of these methods and uncertainty budgets are provided. It is shown that an uncertainty, with respect to solar exo-atmospheric irradiance, of <3%, one sigma, can be attained for each method and that each can, if needed, be related to national laboratory standards.

Posters:

MODIS Calibration presented at Fall AGU '95

P. N. Slater, S. F. Biggar, P. R. Spyak, and K. J. Thome

ABSTRACT

The calibration requirements for the Moderate Resolution Imaging Spectroradiometer (MODIS) are demanding, considerably exceeding those for current operational sensors. For the 20 solar-reflective spectral bands, the uncertainties are to be less than 5% with respect to NIST standards and 2% in reflectance with respect to the sun. The positions of the passbands up to a wavelength of 1 μm are to be monitored to an uncertainty of 1 nm. (All uncertainties are one-sigma values). For the majority of the 16 infrared bands, the uncertainty in measured radiance is specified as 1%. Band-to-band registration is to be less than a fifth of a detector. This Poster briefly describes how the calibration requirements are to be met.

Ground-based Satellite Calibrations presented at 1995 University of Arizona Student Showcase

C. L. Gustafson

ABSTRACT

Remote sensing has become more important in recent years to the civilian population due to the recent interest in determining global change. The remote sensing group at the University of Arizona is involved in NASA's Earth Observing System to determine global change. The group is primarily involved in developing methods to calibrate satellites to allow us to determine if the satellite is changing over time or if it is the earth's environment that is changing.

I present here an example of how a calibration is done for two satellites. The reflectance of a uniform ground site at White Sands Missile Range is measured during a period of time surrounding the time that the satellite is passing over the site. At the same time, and throughout the same day, our group measures various atmospheric properties. Putting these data together we determine how much light reaches the satellite. Using this information and the satellite image we calibrate the satellite's sensors and monitor its changes over time.

My set up includes some of the instruments we use for determining the atmospheric variability and surface reflectance, and other materials to give a broad overview of satellite calibration.

Submitted conference abstracts:

Radiometric cross-calibration for a wide spectral range imaging spectrometer (HYDICE) submitted to SPIE '96 - Denver

S. F. Biggar, E. F. Zalewski, D. J. Kelch, T. G. Chrien, and P. N. Slater

ABSTRACT

The radiometric calibration of HYDICE depends on the performance of an in-flight calibration unit (FCU2) and a ground unit (FCU1) which is also available as a back-up to the flight unit. One of these units, which are similar to filtered integrating sphere sources, is moved under HYDICE before and after each image acquisition. The absolute calibration of the FCUs was initially transferred from NPL via a precision radiometric source (PRS). The transfer of the absolute calibration to the PRS and the FCUs and their stability has been determined by comparing their outputs with that of several calibrated sources and a stable transfer radiometer. Results of the comparisons are presented. Recommendations for future work to improve the absolute calibration of HYDICE are included.

Out-of-spectral-band response for a wide spectral range imaging spectrometer (HYDICE) submitted to SPIE '96 - Denver

S. F. Biggar, P. N. Slater, R. W. Basedow, and W. S. Aldrich

ABSTRACT

The effect of the out-of-band spectral response of a sensor is analyzed in terms of its influence on radiometric stability. A laboratory experiment was conducted on HYDICE using six monochromatic sources covering the instrument's spectral range. Results are compared to those of some filter instruments.

Cross-Calibration of Two Small Footprint Sensors submitted to IGARSS'96

C. L. Gustafson and K. J. Thome

ABSTRACT

This paper presents a method for determining the calibration of a small footprint satellite sensor using another small footprint system. The work uses the Systeme Pour l'Observation de la Terre (SPOT) 3 - High Resolution Visible (HRV) Sensor and Landsat 5 - Thematic Mapper (TM) to determine calibration coefficients for TM using HRV given the different look angles, bandpasses, crossing times and footprints. The cross-calibration results are referenced to the reflectance-based vicarious calibration results from October 8 and 9, 1994, from White Sands Missile Range, NM. Although the images are from two different days the atmospheric and reflectance data are very similar and both satellites had near-nadir views.

The image correlation is done using the image processing program Erdas Imagine and selected ground control points (GCP). The GCPs are chosen based on permanence and distribution in the image. For all three sets of bands used, the same set of GCPs are chosen so that all three bands are identically correlated.

Bands 1, 2, and 3 of HRV, are used to calibrate bands 2, 3, and 4 of TM. The initial attempt of cross-calibration does not account for spectral differences. The calculated calibration coefficient for Chuck Site for TM is between 1 and 4% of the reflectance-based values. Several other sites are also used with dark areas providing the worst results. Other bright areas have errors ranging from about 1 - 12%. Areas within the gypsum dunes have results within the 1-4%

range. To determine misalignment effects, the TM image is moved relative to the HRV image. This produced changes of less than 1% for up to a 40 meter misalignment.

Evaluation of Railroad Valley Playa For Use In Vicarious Calibration submitted to SPIE'96 - Denver
K. P. Scott, M. R. Brownlee, K. J. Thome

ABSTRACT

The results of a study of Railroad Valley Playa, located 100 miles east of Tonopah, Nevada are presented. The primary objective of this study is to determine the playa's suitability as a satellite calibration target. We present the search algorithm used initially to identify the site from satellite imagery. The search mainly focuses on locating areas in imagery that have large spatial extent, spatial uniformity, and high surface reflectance. We present the results of several field campaigns to the site to further examine the playa's surface characteristics. These studies include spectral surface reflectance over the 0.4-2.0 micron range, sample bidirectional reflectance characteristics, and the spatial uniformity of the overall playa.

The target is intended to be used for in-flight radiometric calibration using the reflectance-based approach for small footprint sensors. It will also be used for a cross-calibration approach where one sensor's calibration is transferred to another sensor. We present preliminary error estimates in these two methods from using the Railroad Valley site.

In-flight radiometric stability of HYDICE for large and small uniform reflectance targets submitted to SPIE '96 - Denver

P. N. Slater, R. W. Basedow, and W. S. Aldrich

ABSTRACT

The in-flight radiometric stability of images formed in a single spectral band of HYDICE has been examined under two conditions. In the first, the stability of the combined response of the on-board calibrator and HYDICE was checked by repeated image acquisitions over small targets, a few pixels in size. The second condition was similar to the first except the image acquisitions were of a uniform, extended target. In the case of the small targets, it is shown that radiometric accuracy is closely related to target contrast. This has important consequences for the empirical line calibration method. Both the small and extended targets initially gave varying results. Efforts to reduce the variations will be described together with recommendations for further work.

In-flight radiometric calibration of HYDICE using a reflectance-based approach submitted to SPIE '96 - Denver

K. J. Thome, C. L. Gustafson, P. N. Slater, and W. H. Farrand

ABSTRACT

The reflectance-based method is used to determine an absolute radiometric calibration of the HYDICE sensor. Results are given for data collected at Ivanpah Playa, California on June 20, 1995. This paper describes the reflectance-based method as applied to the hyperspectral case of HYDICE. The method uses a modified version of a Gauss-Seidel radiative transfer code to predict the at-sensor radiances used to compute the calibration coefficients. Coefficients were obtained from several overflights of the target area showing that calibration coefficients are obtained to better than 10% in all bands not affected by strong gaseous absorption, and better than 5% in the visible and near-infrared.

Sensitivity analysis and validation plans for the retrieval of surface reflectance from ASTER
submitted to SPIE'96 - Denver

K. J. Thome

ABSTRACT

A look-up table approach is planned for the atmospheric correction of ASTER data in the solar reflective region. As part of the work to develop this atmospheric correction a sensitivity analysis of top-of-the-atmosphere radiances to changes in aerosol properties has been done. The results presented here use a Gauss-Seidel iteration radiative transfer code to examine effects of changes in aerosol parameters on retrieved surface reflectance. For reflectances greater than 0.1, the surface reflectance retrieval is most sensitive to changes in the aerosol complex index of refraction. At low reflectances, the retrieval is most sensitive to the aerosol scattering optical depth and size distribution. The impact of these results in determining a validation method is discussed.

Papers in preparation:

Characterization of a sky-scanning radiometer and its use for vicarious calibration to be submitted to *Applied Optics*

C. G. Deschappelles, K. J. Thome, and C. L. Gustafson

ABSTRACT

The reflectance-based, absolute-radiometric calibration of satellite sensors relies on ground-based, solar-radiometer measurements to infer atmospheric aerosol properties and scattering phase function. Recently, an automated solar radiometer has been used for these calibrations. This radiometer also has the capability of measuring sky radiance which can also be used to determine aerosol scattering phase function. This paper shows that total optical depths from this new system agree to within 1.5% to those obtained from a manual solar radiometer used for this work in the past. We also show the choice of scattering phase function, derived from optical depths only or by including sky radiance measurements, has only a minor effect on the predicted at-satellite radiances for the wavelengths measured, for the satellite calibrations done at White Sands. For typical White Sands conditions, there is, at most, a 1% difference between the results of assuming a Junge size distribution and the results of obtaining a size distribution from inverting the sky radiance measurements. Over dark targets, such as a lake or other body of water, the effects are much more significant.

Evaluation of the applicability of solar and lamp radiometric calibrations of a precision solar radiometer operating between 300 and 1025 nm

B. Schmid, P. Spyak, S. Biggar, S. Wehrli, C. Matzler, and Kampfer

Reflectance properties of pressed Algoflon F6: a replacement reflectance standard material for Halon to be submitted to *Applied Optics*

P. R. Spyak and C. Lansard

ABSTRACT

The standard ultraviolet to short-wave-infrared diffuse reflectance material, Halon TFE-type G-80, is no longer available. As a result, a new diffuse-reflectance standard material must be found. Here, it is shown that Algoflon F6 is an appropriate replacement by presenting measurements of various spectral-reflectance properties of Halon and Algoflon F6. The measurements include: spectral bidirectional reflectance factor (BRF), spectral hemispherical reflectance, sample repeatability, and sample lifetime.

The effects of atmospheric absorption on laboratory measurements to be submitted to *Applied Optics*
P. R. Spyak, J. L. LaMarr, and K. J. Thome

In-flight radiometric calibration of Landsat-5 Thematic Mapper from 1984 to 1994 to be submitted to *Remote Sensing of the Environment*

K. J. Thome, S. F. Biggar, D. I. Gellman, P. R. Spyak, P. N. Slater, M. S. Moran

ABSTRACT

The reflectance-based method is used to determine an absolute, radiometric calibration of Landsat-5 Thematic Mapper for the solar reflective portion of the spectrum for both level-0 and level-1 data. Results are given for three calibration campaigns at White Sands Missile Range in New Mexico in 1992, 1993, and 1994 and these results are compared to those obtained from data collected between 1984 and 1988. The retrieved calibration coefficients indicate a degradation in Thematic Mapper when compared with the preflight calibration coefficients. The degradation is much larger for the shorter wavelength bands than the longer wavelength bands with differences of 27%, 20%, 15% for bands 1, 2, 3 respectively, between the preflight values and those obtained in 1994. The degradation in bands 4, 5 and 7 are within the uncertainties of the method.